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INVESTIGATION OF CO_X REDUCTION SYSTEM PROTOTYPE AT 1000CC VEHICLE REMOVAL GASES USING KNIFE-TO-PLATE GLOW DISCHARGE PLASMA

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Abstrak

CO_x reduction of exhaust gases from 1000cc vehicle has investigated using prototype reactor of corona glow discharge of plasma. Knife-to-plate electrodes configuration is used inside the reactor with DC high voltage source to generate corona glow discharges plasma. In this experiment, we investigate voltage-current parameter in conducting effective corona plasma development. CO_x reduction is done under two-corona condition for four-time duration exhaust gases hold in plasma condition. Results shows that biggest Decomposition Efficiency value of CO and CO_2 are happens along with longer exhaust gases hold in plasma condition, with the best result for CO is 83,07% and for CO_2 is 65,81%. This experiment also investigate knife electrode rotation influences in CO_x reduction efficiency with result that lower rotation velocity gives more sophisticated Decomposition Efficiency rather than the higher one. The best Decomposition Efficiency for knife electrode rotation for CO is 68,07% and for CO_2 is 63,26%. Reduction crust that is found and investigate using anion-cation and FTIR analysis in this experiment shows the presence of NH_4^+ cation and CO_3^{2-} anion that give a hypothesis that one of the compound formation from reduction crust is ammonium carbonate. A hypothetical chemical reaction process is presented to investigate how it formation build distribusi.

Introduction

Combustion from hydrocarbons fuels will emitt an exhaust gases that contain pollutant gases such as NO_x, SO_x, and CO_x, etc. [1-4]. To prevent it multiplication in air that can be harmful to our health, a reduction process has take places using a non-thermic plasma technology at atmospheric temperature [5-7]. Our group has done several researches in CO_x reduction using pin-to-plate and wire-to-plate electrodes under process of glow discharge plasma at atmospheric temperature. Our group past researches were conducted to investigate pure and exhaust CO_x reduction and gave significant result of it efficiency in the presence of additive gases (NH_3, Ar, H_2O) that made plasma condition easier to happen [8-10]. The research also indicates hypothetically the chemical compound of the crust inside the reactors as evidence that reduction process occurs inside the reactors.

In this experiment, CO_x reductions of CO and CO_2 from 1000cc vehicle exhaust gases were investigated using knife-to-plate glow discharge plasma reactor. Field of test was carried out under two-corona plasma condition. Additives added was not used as it presence naturally had come from combination between fuel and air in vehicle combustion process.

Voltage-current parameter of two-corona development also investigated in this experiment in order to found condition that can maintain the chemical chain reactions to occur inside the reactor. Knife electrode was set to be static and rotated to investigate electrode rotation influences of reduction efficiency.

Experimental set up

The plasma reactor basically consist of a cylindrical plate and knife plate placed on a massif cylindrical plate as an electrodes which was based on a DC glow discharge as pictured in figure 1. Positive and negative corona plasma was developed by connecting knife electrode with positive output of the power supply for positive corona plasma and connecting knife electrode with negative terminal of the power supply for negative corona plasma [11-12]. The discharge gap was set to be 0,7 cm. the input voltage was given by DC high power supply that can provide voltage up to 10 kV (BATAN DC 767) with the output current was measured using an analog ampere meter (Metra Point MA 3E).

Exhaust gases from muffler move in to one of the reactor pipe and move out from the other one, which is placed at each corner of the cylindrical plate. Reduction efficiency was measured using Gas Analyzer (Tecnotest type 488). Knife electrode was rotate using DC motor that generated using DC low power supply made by us with rotation velocity measured using tacho meter (HIOKI 3402).

In this experiment, CO_x reduction of exhaust gases were threat in positive and negative corona plasma conditions. CO_x that were reduced in this experiment were focused on CO and CO_2. Knife electrode was set to remain static when exhaust gases were investigated under positive and negative corona condition for 2.10^{-2}s (the gases flows inside the reactor), 30s, 180s, and 300s. For knife electrode set to rotate, rotation velocity was given for 100-rpm, 300-rpm, and 600-rpm. For these two-rotation velocities, exhaust gases were hold in negative corona plasma conditions for 2.10^{-2}s (the gases flows inside the reactor), and 90s. The exhaust gases move into the reactor with constant velocity about 7,33 m/s. CO_x removal efficiency, or in this thesis known as CO_x Decomposition Efficiency (DE), were investigate by calculating CO_x initial concentration (C_o) and CO_x concentration after plasma condition (C_t) using equation [13]:

CO_x Decomposition Efficiency (DE) =

$$\left(1-\frac{C_t}{Co}\right)\times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

We used Fourier transfer infrared spectroscopy (FTIR) analysis (Shimadzu Hyper FTIR-8201PC) to analyze chemical bound from the crust inside reactor that occur as a residue after reduction process happened. Qualitative Anion and cation analysis of the crust also taken place to bring more information about the chemical compound and to convince FTIR results of it chemical bound.

Results and discussions

A. Voltage-current parameter to develop corona plasma condition

Voltage-current parameter investigation to found corona plasma development characteristic is figured in figure 2 to 3. It was as figured in table 1., that corona discharge inside the reactor, which was filled with exhaust gases from 1000cc vehicle, occur vary from 1,7-2,2 kV with current up to 110,0 μA. Corona discharge range were decided when audible noise and visible light effect inside the reactor observable [14].

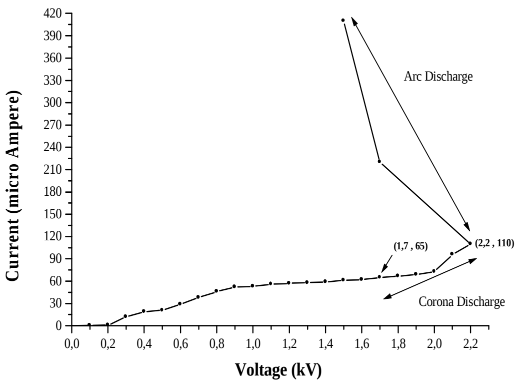
Table 1. Voltage-current parameter for corona development inside the reactor

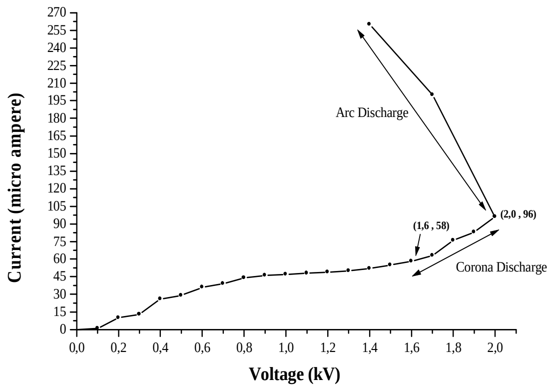
Type of corona	Knife electrode treatment	Corona voltage (kV)	Current (μA)
Positive	Static	1,7-2,2	65,0-110,0
Negative	Static	1,6-2,0	58,0-96,0

Negative	100 rpm	1,6-2,0	62,0-85,0
Negative	300 rpm	1,6-2,0	56,0-86,0
Negative	600 rpm	1,6-2,0	63,0-89,0

Figure 2 to 3 presents current development as a function of voltage in characterizing corona discharge range and arc discharge limit to happen. Figure 2(a) and 2(b) corresponds to positive and negative corona development inside the reactor with knife electrode remains static. Figure 3(a) to (c) corresponds to a negative corona development inside reactor with knife electrode rotated at 100-rpm, 300-rpm, and 600-rpm.

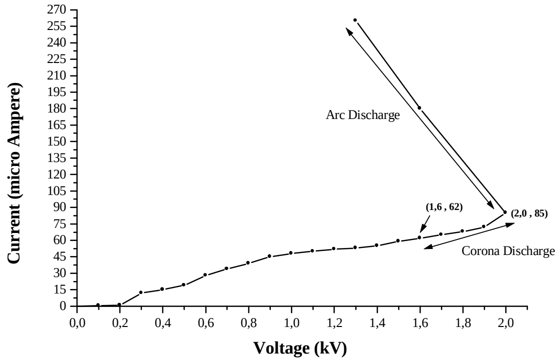
Figure 3(a) to (c) shows that rotation velocity does not give any significant differences on corona range developments within voltage range vary from 1,6 – 2,2 kV. However, as it compares with figure 2(b), we can analyze that corona discharge is easily transit to arc discharge when knife electrode rotating rather that when it static. From it comparison, we know also that corona discharge has a more widely range when knife electrode remains static. Voltage-current parameter shows that corona plasma development for CO_x reduction investigation is best given at voltage before arc discharge occurs.

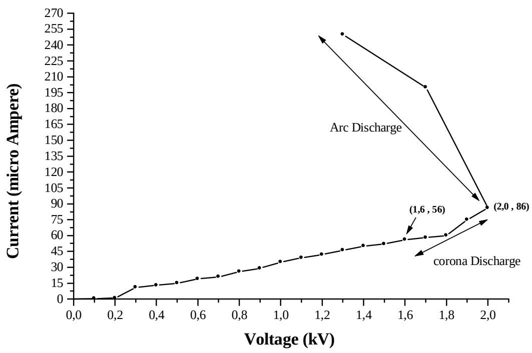




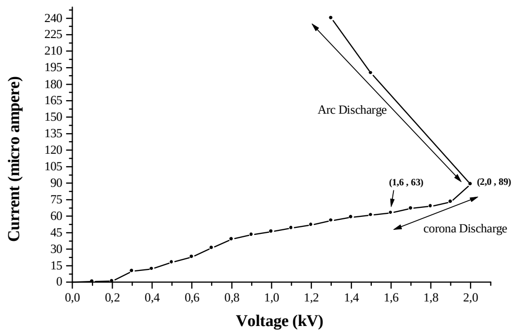
(a) **(b)**

figure 2. Voltage-current parameter on corona plasma development inside the reactor when knife electrode remains static. (a) Positive corona. (b) Negative corona.





(a) **(b)**

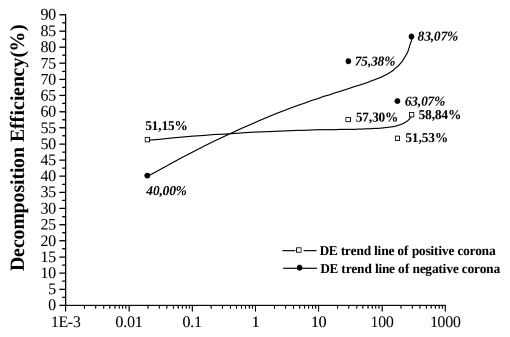


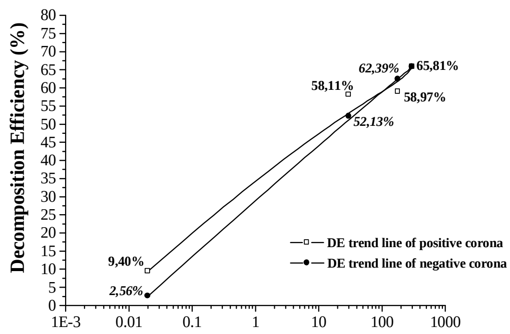
(c)

Figure 3. Voltage-current parameter on negative corona plasma development inside the reactor when knife electrode rotated. (a) 100-rpm. (b) 300-rpm. (c) 600-rpm.

B. CO_x Decomposition Efficiency

This experiment were investigate CO_x Decomposition efficiency for CO and CO_2 reduction efficiency at four time duration exhaust gases holds under two corona plasma condition. Decomposition Efficiency of CO, as figured in figure 4(a), shows that negative corona can reduce CO more effective rather than the positive ones. This experiment found the best Decomposition Efficiency result at 83,07% under negative corona plasma condition at 300 second exhaust gases holds in plasma. For CO_2 Decomposition Efficiency as figured in figure 4(b), both positive and negative corona give relatively same results of Decomposition Efficiency with the best results was found under positive and negative corona condition at 65,81% at 300 second exhaust gases holds in plasma. Both figure 4(a) and (b), figures that more best results on CO_x Decomposition Efficiency is gained when more longer exhaust gases holds under plasma condition as more sufficient chemical chain reaction occurs.





(a) **(b)**

Figure 4. CO_x Decomposition Efficiency under corona plasma conditions for knife electrode remains static. (a) CO, (b) CO_2

C. Knife electrode rotation influence in CO_x Decomposition Efficiency

Knife electrode rotation in this experiment was set in three-rotation velocity. Rotation treatment was conduct to investigate it influence on CO_x reduction efficiency. Exhaust gases time duration were set for two-time duration exhaust gases holds under negative corona plasma condition. Figure 5(a) and (b) shows rotation velocity effect in CO_x reduction efficiency, where low rotation velocity gives results that are more effective rather than the higher one. This experiment found that the best Decomposition Efficiency of CO and CO_2 were 68, 07% for CO and 63, 26% for CO_2 at 100-rpm knife rotation velocity with exhaust gases holds in plasma for 90 second.

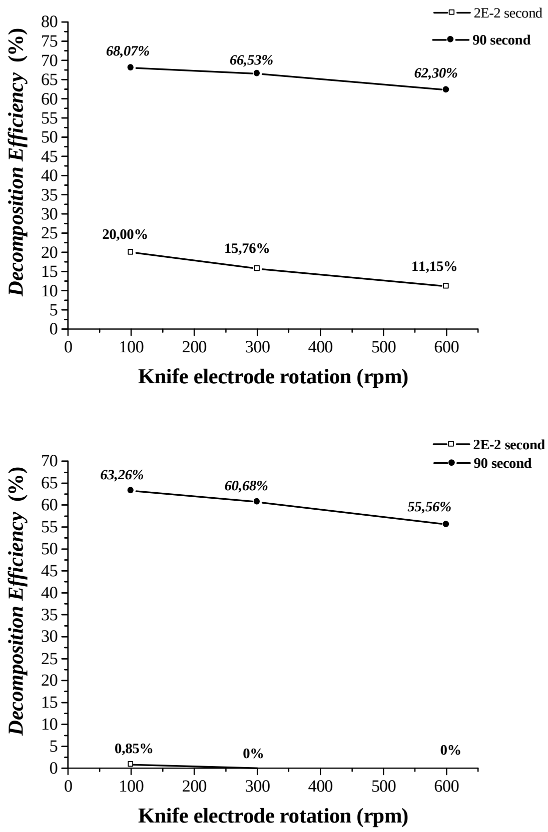


Figure 5. Knife electrode rotation influences in CO_x decomposition efficiency under negative corona plasma. (a)CO. (b)CO_2.

D. Anion, Cation, and FTIR analysis of crust residue from CO_x reduction process

FTIR absorption bands as figured in figure 6., shows several chemical bound from the crust that can indicate crust chemical compound. From it absorption bands, investigation gives result of seven possibility of chemical bound of the crust as it figured in table 2. These chemical bound give us first indication that chemical chain reaction mechanism has occurs inside the reactor. It also indicate that CO_x and other gases from exhaust gases were react and construct some new chemical bounds. To convince this indication, we use qualitative anion-cation chemical analysis to investigate the crust chemical compound and found several anion-cation compound as it figured in table 3. FTIR and anion-cation analyses shows anion-cation compounds of the crust, which are ammonium (NH_4^+) and carbonate (CO_3^{2-}). This results was convinced along with no other anion-cation compounds that match FTIR chemical bounds data.

The presences of ammonium (NH_4^+) and carbonate (CO_3^{2-}) in reduction crust brings investigation to develop a hypothesis of it construction reaction by first giving several reaction possibilities from [15] as shown below:

CO_2 dissociation:

$e + CO_2 \longleftrightarrow CO + O^* + e$ (2)

$H + CO_2 \longleftrightarrow CO + OH$ (3)

NO_2 dissociation:

$e + NO_2 \longleftrightarrow NO + O^* + e$ (4)

NO dissociation:

$$NO + O^* \longleftrightarrow N^* + O_2 \quad (5)$$

H_2O dissociation :

$$O(^1D) + H_2O \longrightarrow OH + OH \quad (6)$$

Carbonate (CO_3^{2-}) construction was consider to explain by reaction of O* radical which was occurs from CO_2 and NO_2, react more further with CO_2 or CO to construct CO_3^{2-} bound by these hypothetical reaction :

$$O^* + CO \longrightarrow CO_2 \quad (7)$$
$$O^* + CO_2 \longrightarrow CO_3^{2-} \quad (8)$$

Ammonium (NH_4^+) construction was consider to explain hypothetically by these continuing reaction between N* radical with H^* radical and finally with H^+ as follow :

$$N^* + H^* \longrightarrow NH^* \quad (9)$$
$$H^* + NH^* \longrightarrow NH_2^* \quad (10)$$
$$H^* + NH_2^* \longrightarrow NH_3 \quad (11)$$
$$H^+ + NH_3 \longrightarrow NH_4^+ \quad (12)$$

From ammonium (NH_4^+) and carbonate (CO_3^{2-}) hypothetical construction reaction, this experiment hypothetically states that one of the chemical compound from the crust inside the reactor was ammonium carbonate $(NH_4)_2CO_3$ under this hypothetically reaction :

$$CO_3^{2-} + 2\,NH_4^+ \longrightarrow (NH_4)_2CO_3 \quad (13)$$

Table 2. FTIR chemical bound

No.	Wave number (1/cm)	Intensity (%T)	Chemical bound
1	875,6	35,227	CO_3=
2	1384,8	33,119	CH_3-C bend
3	1541,0	33,680	-NH-
4	1624,0	32,204	$-NH_2$
5	2852,5	34,073	$-CH_2-$
6	2922,0	32,457	$-CH_2-$
7	3421,5	26,732	$-NH_2$ stretch

Table 3. Anion-cation test results

Anion-cation test	results
Ammonium (NH_4^+)	Positive
Carbonate (CO_3^{2-})	Positive
Nitrite (NO_2^-)	Negative
Nitrate (NO_3^-)	Negative
Sulfate (SO_4^{2-})	Positive
Sulfite (SO_3^{2-})	Positive

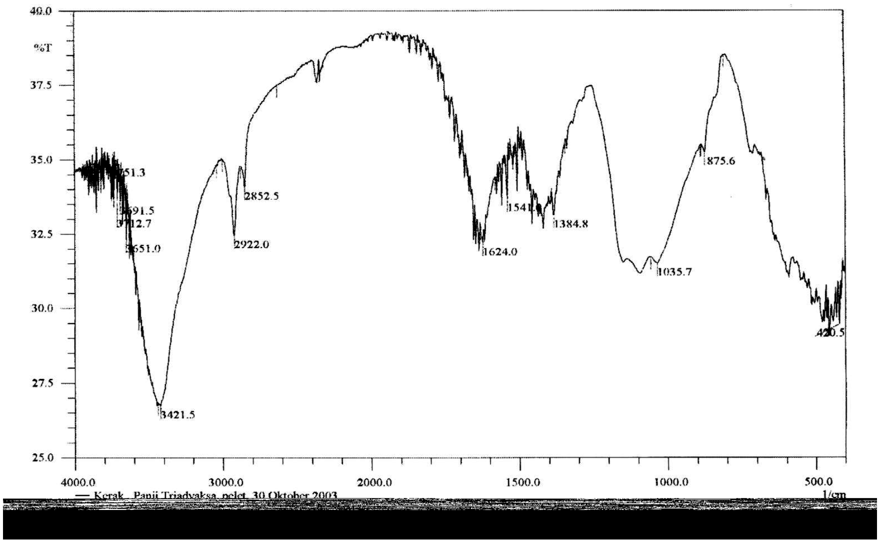


Figure 6. FTIR absorption band from the crust sample

I. Conclusions

Experiments were conducted on CO_x reduction test from 1000cc exhaust gases using knife-to-plate glow discharge plasma reactor for CO and CO_2. Further, plasma treatment was carried out on knife electrode rotation influences in the reduction process. The chemical compound from the crust inside the reactor after reduction process was investigated and hypothetically gave results within it reaction. The following conclusion were drawn from the results :

- Treatment of glow discharge plasma for 1000cc exhaust gases inside the knife-to-plate reactor resulted in 1,6-2,2 kV corona plasma development voltage.
- CO_x Decomposition Efficiency best results is gained within longer exhaust gases holds under plasma condition.
- The biggest Decomposition Efficiency for CO in this experiment is 83,07% under negative corona condition, and for CO_2 is 65,81% under positive and negative corona condition. Both CO and CO_2 Decomposition Efficiency occur at 300 second time duration under plasma condition with the knife electrode remains static.
- Knife electrode gives significant result in reducing CO_x at low rotation velocity.
- Knife electrode rotation gives the best results of CO_x Decomposition Efficiency at 68,07% for CO and 63,26% for CO_2 under 100-rpm knife electrode rotation velocity and the gases holds under plasma condition for 90 second.
- One of the chemical compound from the crust inside the reactor after CO_x reduction process occurs in this experiment hypothetically recognize as ammonium carbonate ($(NH_4)_2CO_3$).

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